DEVELOPMENT OF PERFORMANCE SPECIFICATIONS FOR THE OCCUPANT CLASSIFICATION ANTHROPOMORPHIC TEST DEVICE (OCATD)

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ABSTRACT

Advanced airbag systems use a variety of sensors to classify vehicle occupants so that the airbag deployment can be modulated accordingly. One potential input to such systems is the distribution of pressure applied to the seat surface by the occupant. However, the development of such systems is hindered by the lack of suitable human surrogates. The OCATD program has developed two new surrogates for advanced airbag applications representing a small adult woman and a six-year-old child. This paper describes the development of performance specifications for the OCATDs based on a study of the seat surface pressure distributions produced by vehicle occupants. The pressure distributions of sixty-eight small women and children ranging in body weight between 23 and 48 kg were measured on four seats in up to twelve postures per seat. The data were analyzed to determine the parameters of the pressure distribution that best predict occupant body weight. Target values for these parameters were then developed for the two OCATD sizes. Measurements of pressure distributions produced by the OCATDs showed good agreement between the human-derived targets and the OCATD performance.

INTRODUCTION

Recent changes in U.S. Federal Motor Vehicle Safety Standards have led to the rapid introduction of occupant sensing and characterization systems intended, in part, to suppress airbag deployment when the corresponding seating position is not occupied by a normally positioned adult. One obstacle to the development and implementation of these systems is the lack of appropriate human surrogates for use in testing and validation. For example, some of the currently available occupant classification systems use seat surface pressure distribution as one input to the classification algorithm. However, previous investigations at UMTRI have shown that existing human surrogates, such as the Hybrid-III and THOR crash dummies, produce humanlike seat surface pressure distributions that are visually dissimilar from those produced by similarly sized humans (Reed et al. 1999). Development and testing of occupant classification systems also requires testing surrogates in a wide range of postures, but many postures that are possible for humans cannot be attained with crash dummies.

In response to these needs, First Technology Safety Systems (FTSS) led an effort to develop two surrogates for occupant characterization applications, representing a small adult woman and a typical six-year-old child. These Occupant Classification Anthropomorphic Test Devices (OCATD — pronounced “oh-cat”) are designed to be quantitatively representative of humans in the corresponding anthropometric categories with respect to external anthropometry, skeletal linkage, body mass, and segment mass distribution. These devices are also designed to produce seat surface pressure distributions that are quantitatively representative of human vehicle occupants.

This paper describes part of the research conducted at UMTRI during the OCATD development program (Reed et al. 2000, 2001). Seat surface pressure distributions of sixty-eight small women and children ranging in body weight between 23 and 48 kg were measured on four seats in up to twelve postures per seat. The data were analyzed to determine the parameters of the pressure distribution that best predict occupant body weight. Target values for these parameters were then developed for the two OCATD sizes. Measurements of pressure distributions produced by the OCATDs showed good agreement between the human-derived targets and the OCATD performance.

METHODS

Subjects

Sixty-eight women and children were recruited via newspaper advertisements and word of mouth. Fifteen of the children were similar in stature and weight to the OCATD six-year-old (OCATD6) targets, nine women fit within the OCATD small adult female (OCATD5) category, and thirty-one children had stature and weight between the two

OCATD categories. Thirteen women and teenage girls who were close to the OCATD5 category requirements were also tested.

Seats

Four front vehicle seats were selected to span a range of seat stiffness and contour. Seats were selected from among those available to be relatively free of seam lines that would produce artifacts in the pressure distributions. A simplified seat (Seat 0) constructed with 100-mm-thick soft foam slabs was also used. The seats were mounted on the test platform so that the seat H-point was approximately 270 mm above the heel rest surface, a seat height typical of a midsize sedan. An armrest was affixed to the floor at the right of the seat approximately 150 mm above the H-point. The floor was covered with a sheet of Teflon so that the subjects could readily slide their heels forward for some test conditions.

Pressure Distribution Measurement System

Pressure distributions were measured using an Xsensor system, comprised of two pressure-sensing mats and a computer interface. The mats are about 3 mm thick and can be flexed on multiple axes so that they conform easily to the deflected seat contour. Each mat contains 1296 capacitative sensors arranged in a 36 x 36 array. Each sensor is square, measuring 12.5 mm (0.5 inch) on each side. The sensors were sampled at 10-second intervals during data collection. For testing, the sensing mats were affixed to the seat using double-sided cloth adhesive tape. Clips were placed on each mat to mark the seat H-point location, as measured by the SAE J826 H-point machine.

Postures

Pressure distributions were measured in a range of postures, listed in Table 1. Fifteen postures were selected to produce a wide range of pressure distributions and do not represent the expected distribution of posture prevalence in the field. Children were tested in a larger range of postures than adults, including several kneeling postures.

Table 1.
Test Postures

Normal	Kneel Backwards**
Knees Up*	Stand**
Knees Up**	Kneel Sideways**
Leaning Forward	Sitting on Wallet*
Lean Right	Wearing Coat*
Legs Crossed	Normal Recline (30 degrees)
Slouched	Extreme Recline (45 degrees)
Sit on Foot**	

* Adults only
** Children only

Procedures

Testing was conducted in an UMTRI laboratory. The purposes and methods of testing were explained to each subject and (for children) their parent or guardian, and written consent was obtained. Subjects were tested in the five seats in a random sequence. The subjects wore normal indoor clothing. Each adult subject was tested in eight prescribed postures and each child in twelve prescribed postures, in the same order, for each seat (see Table 1). Each of the postures was maintained for about 30 seconds as data were collected.

RESULTS

Seat surface pressure data were analyzed with three objectives:

1. determine the pressure-distribution parameters that provide the greatest ability to classify occupant size,
2. identify performance targets for the OCATD devices with respect to seat surface pressure distribution, and
3. assess the performance of the OCATDs relative to their performance targets.

The analysis used data from the seat cushion mat exclusively, since most current pressure-based occupant classification systems use primarily seat cushion sensors. Most analyses were also conducted using data from seat 0 only (the flat-foam seat), to avoid pressure artifacts caused by seat seams.

Typical Pressure Data

Figure 1 shows a typical pressure distribution from the seat cushion pad, with several features labeled and with pressure levels displayed with different colors. In this paper, all pressure distribution illustrations are from the seat cushion and are best viewed in color. The front of the seat cushion is at the top of each image. The isolated pressure peak at the left side of the image is produced by a clamp applied to mark the seat H-point location.

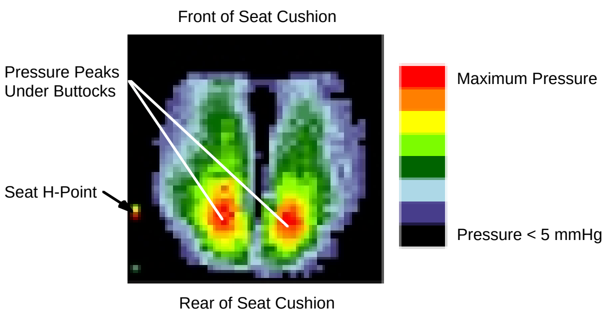


Figure 1. Typical pressure distribution in a normal posture, with various features labeled.

Pressure distributions were similar across seats, but were strongly affected by posture in each seat. Across subjects, the primary differences were in width and area. Table 2 shows typical pressure distributions from a small adult woman and a six-year-old in seat 4, a firm seat with minimal contouring.

Table 2 illustrates that the differences between adult and child pressure distributions are primarily a matter of width and contact area. The thighs of most children in the OCATD6 category were shorter than the seat cushions in all seats except seat 0. In the normal posture, most children did not contact the cushion in the distal thigh area, but areas of contact were observed at the front edge of the cushion where the child's legs contacted the cushion. In the buttock area, child and adult pressure distributions are similar, except that the child's pressure distribution is smaller.

Posture has a large effect on seat surface pressure distributions. Most seated postures show peaks in the area of the buttocks, corresponding to the ischial tuberosities of the pelvis, but these peaks are altered when the sitter leans to the side. Interposing a wallet or a coat between the sitter and seat affects the pressure distribution considerably, with the coat tending to widen the pressure distribution produced by the child. The kneeling postures produced pressure distributions that are visually very dissimilar from the normal seated pressure distributions. Differences in pressure distributions across seats are smaller than differences across postures and body sizes.

Parameter Definition and Calculation

The first step in the quantitative data analysis was the identification of parameters that could be used to describe the seat surface pressure distributions. The seat cushion pressure distribution is comprised of a 36 x 36 array of pressure values, typically ranging from zero to over 100 mmHg. These values can be used to calculate a large number of possible statistics or parameters that describe the pressure distribution. For example, the peak pressure, average pressure, and contact area are potentially useful parameters. Useful parameters are those that (1) provide a quantitative description of an important characteristic of the pressure distribution, or (2) are significantly related to a classification variable of interest, such as body weight. The analysis demonstrated that most of the variables that fall into the second category are also members of the first category.

Table 3 lists a subset of the parameters that were evaluated. The parameters include measures of seat contact width and area, a pseudoweight calculated by summing sensor pressures, and measures of pressure-peak spacing. Detailed analyses were conducted with 42 parameters (Reed et al. 2000).

Values for each parameter were calculated for each seat cushion pressure distribution. The occupant classification potential of each parameter was assessed by determining its relationship with occupant body weight using a linear regression analysis. Figure 2 shows plots of three parameters as predictors of body weight using data from the normal posture and from all postures in seat 0.

In the data from the normal posture, the best prediction of body weight is obtained using a width measure, PeakRowWidthP10, which is the lateral width of the pressure distribution at the fore-aft location of the highest pressure, evaluated using the contact area exceeding 10 mmHg. Similar width measures using both pressure values and quantiles are nearly as effective, giving R^2 values greater than 0.80. The third-best predictive parameter for normal postures is PseudoWeightLb, obtained by summing the pressure across all sensors, multiplying by the sensor area, and expressing the result in pounds.

Table 2.
Pressure Distributions for Two Subjects on Seat 4 in Selected Postures

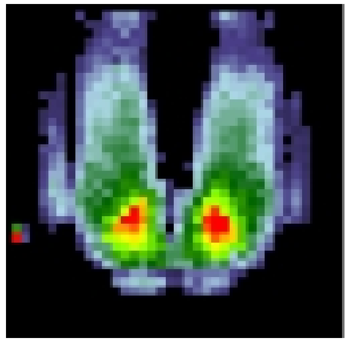
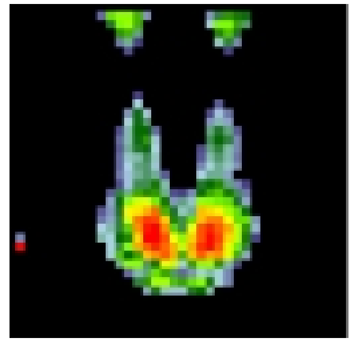
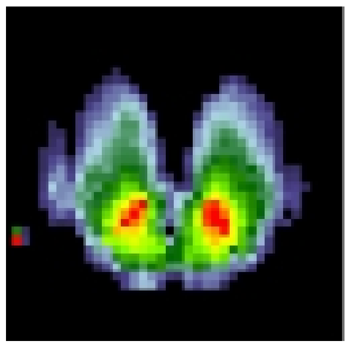
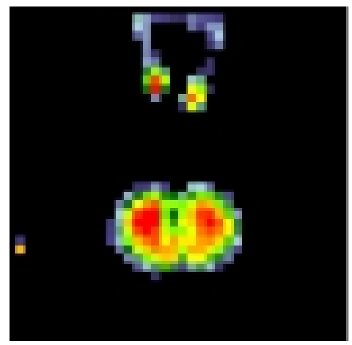
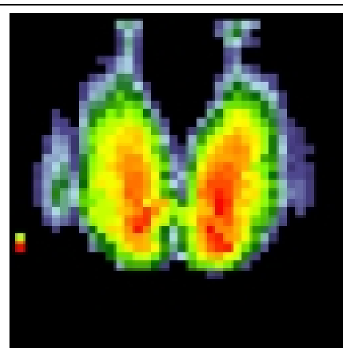
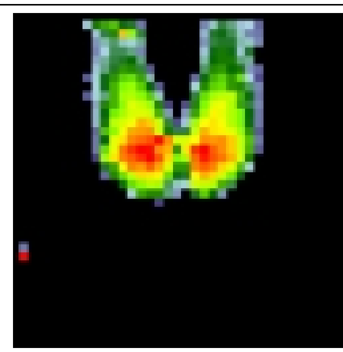
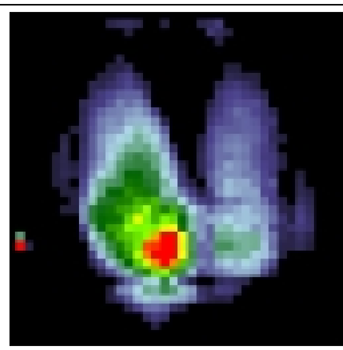
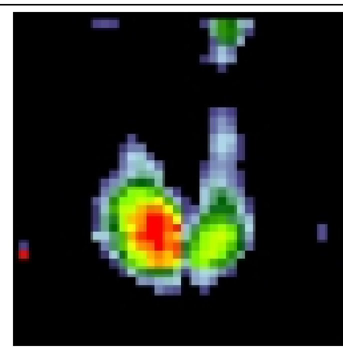
Posture	Typical Small Adult Woman	Typical Six-Year-Old Child
Normal 		
Knees Up 		
Forward 		
Lean 		

Table 3.
Selected Pressure Distribution Parameters

Parameter	Definition (units)	R^2 Normal Posture*	R^2 All Postures*
PeakRowWidthP10	Maximum lateral distance separating sensors reading at or above 10 mmHg in the lateral row containing the highest pressure peak (sensor units)	0.88	0.38
CentroidRowWidthQ20	Maximum lateral distance separating sensors reading at or above the 20th-percentile pressure in the lateral row containing the pressure distribution centroid (sensor units)	0.86	0.21
PseudoWeightLb	Sum of the product of sensor pressure and sensor area (lb)	0.85	0.78
CentroidRowWidthP10	Maximum lateral distance separating sensors reading at or above the 10 mmHg in the lateral row containing the pressure distribution centroid (sensor units)	0.85	0.20
CentroidRowWidthQ10	Maximum lateral distance separating sensors reading at or above the 10th-percentile pressure in the lateral row containing the pressure distribution centroid (sensor units)	0.84	0.20
PeakRowWidthQ10	Maximum lateral distance separating sensors reading at or above the 10th-percentile pressure in the lateral row containing the highest pressure peak (sensor units)	0.84	0.39
AreaP10	Area of the pressure distribution exceeding the 10 mmHg (cm^2)	0.81	0.57
AreaQ20	Area of the pressure distribution exceeding the 20th percentile of pressure (cm^2)	0.79	0.56
AreaQ10	Area of the pressure distribution exceeding the 10th percentile of pressure (cm^2)	0.79	0.57
PeakRowWidthQ20	Maximum lateral distance separating sensors reading at or above the 20th-percentile pressure in the lateral row containing the highest pressure peak (sensor units)	0.78	0.37
InterpeakDistance	Euclidean distance between highest two pressure peaks. Peak locations are identified after passing a 3x3 averaging filter over the data. A peak sensor reading is higher than all other sensor readings within a 7x7 window. Data from the area of the H-point marker are excluded (sensor units**)	0.02	0.00

* R^2 for a linear regression predicting subject body weight from the parameter value.
** Each sensor unit is 0.5 inch (12.7 mm).

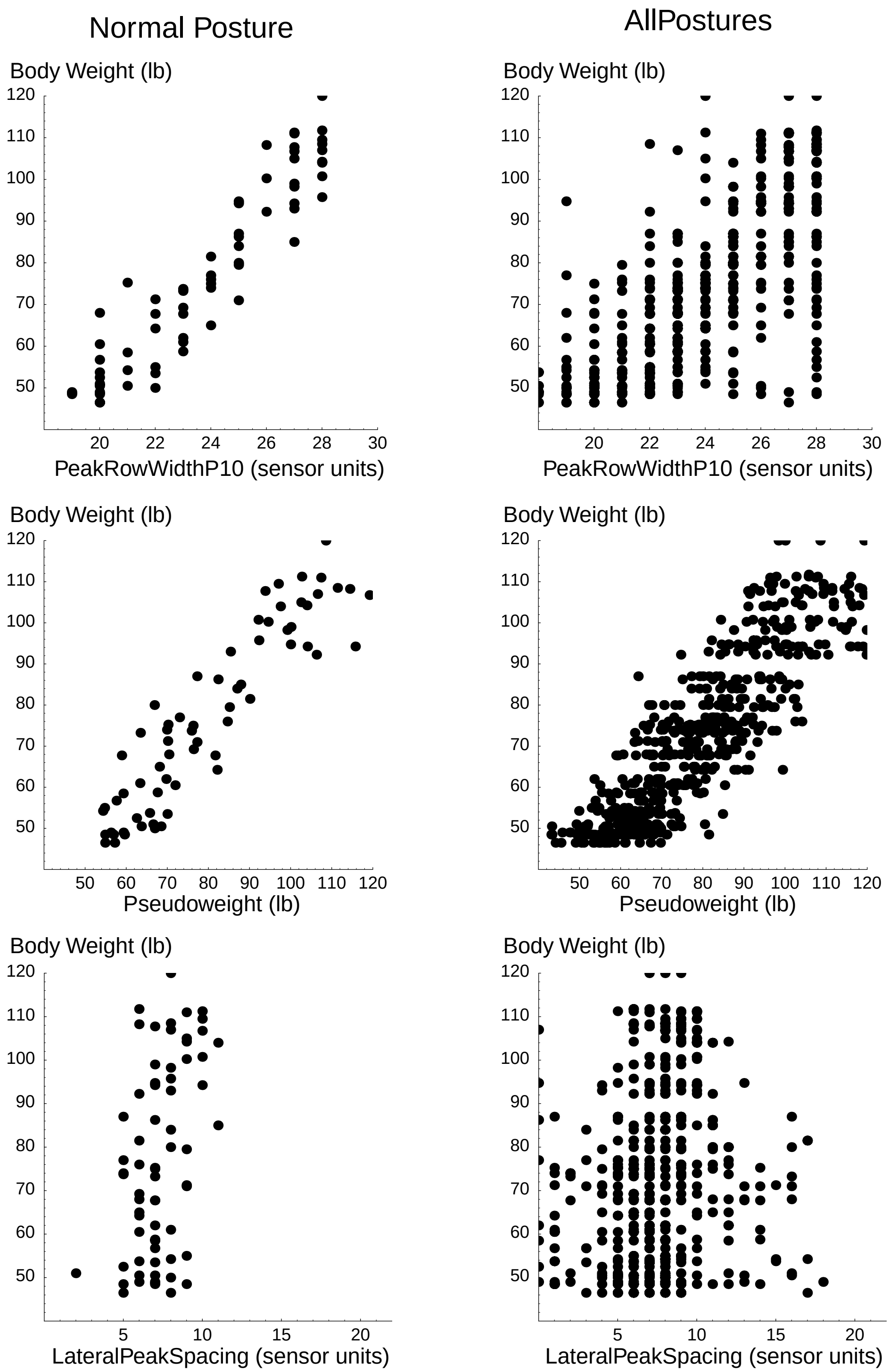


Figure 2. Parameter values (horizontal axis) relative to occupant body weight (vertical axis) for 68 subjects in seat 0 for normal postures (left) and all postures (right). See Table 3 for parameter definitions.

Area measures, such as the area registering more than 10 mmHg pressure, also provide R^2 values better than 0.75. Notably, at least one of the measures commonly thought to be a useful classifier is one of the worst performers. In these normal posture data collected on a soft, flat seat (an idealized scenario), the distance between the two largest pressure peaks is not significantly related to body weight ($R^2 = 0.02$).

Some of the parameters that are most effective in classifying occupants in the normal postures are considerably less effective across postures, reflecting the additional variance introduced by posture changes. The best predictor for all postures is PseudoWeightLb, with an R^2 value of 0.78. The area parameters are the only other parameters for which the R^2 value exceeds 0.5. A variety of the width-related parameters have R^2 values between 0.3 and 0.4. The parameters with the best predictive ability are fairly well correlated in this dataset. Correlation coefficients for data from the normal posture generally exceed 0.9 for the parameters with the best predictive ability. The correlation coefficients drop substantially when data from all postures are considered, but remain significant. As a consequence of the correlation among parameters, using multiple parameters does not improve the prediction of body weight substantially.

OCATD Performance Evaluation

OCATD prototypes were placed in test seats in the postures tested with human subjects to compare the pressure distributions. Figure 3 shows the OCATD5 and OCATD6 in a test seat. A cloth was draped over the pressure mats when testing with the OCATD5 to facilitate positioning the manikin without disrupting the pressure pad placement.

Quantitative Performance Evaluation

Quantitative evaluation of OCATD performance was conducted using the pressure-distribution parameters developed in analyzing data from the human subjects. The regressions predicting the parameter value from body weight for normal postures were used to determine performance targets for the OCATDs. The target OCATD5 and OCATD6 weights of 51.5 lb and 108 lb, respectively, were used with the linear functions for each parameter to obtain parameter targets (Intercept + Slope * Target Weight).

For both the OCATD5, the parameter values calculated from the OCATD pressure data were close to the target values determined from the human subject data. The correspondence between the parameter values calculated for the OCATDs and the corresponding targets is illustrated in Figure 4. The normal distributions in the figure represent the expected distribution of the parameter value for people who match the OCATD reference body weight. Horizontal lines indicate ±1 and ± 2 standard deviations. Scaled deviations between the OCATD and target parameter values are plotted on the vertical axis for the ten parameters that best predicted body weight in the human data analysis.

Figure 3. Measuring the pressure distribution of the OCATD5 (top) and OCATD6 (bottom).

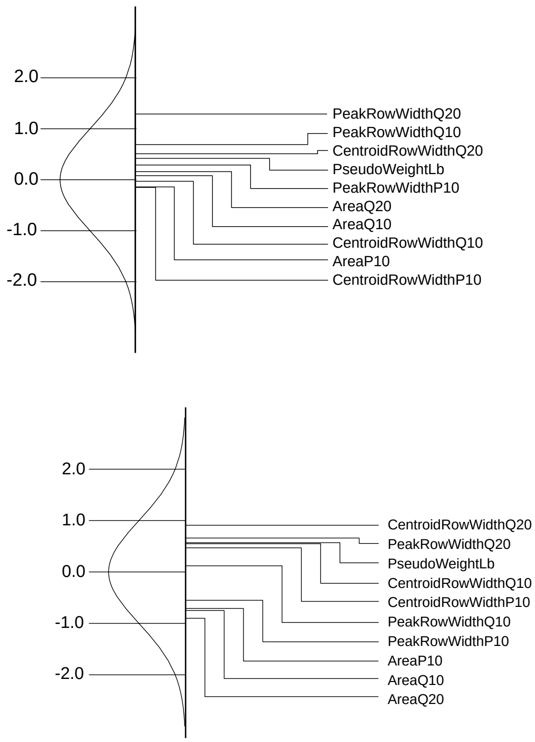


Figure 4. Illustration of OCATD5 (top) and OCATD6 (bottom) performance relative to targets. Vertical axis shows normalized OCATD parameter value in standard deviations relative to human-derived target. See Table 3 and Reed et al. (2000) for definitions of the parameters.

DISCUSSION

This study developed an extensive database of seat surface pressure distributions representing children and adults in a large range of postures and several seats. The data provide a quantitative way to specify and assess the performance of the OCATDs for use with occupant classification systems that include pressure distribution as an input. Most previous studies of pressure distribution in automotive seats have emphasized comfort applications, and parametric analyses have focused on variables related to differences in comfort across seats. In contrast, the analyses in this study are focused on parameters that are usefully related to overall occupant size, represented by body weight.

The analyses were conducted using two scenarios. First, data from an idealized situation, consisting of a soft, flat seat and a single, standardized posture were examined. Occupant classification using pressure distribution should be most effective in this situation. Second, the analyses were repeated using data from a wide range of postures, to determine which parameters were robust to posture change.

A large number of pressure distribution parameters were defined and calculated, a small subset of which were included in this paper. The selection of parameters was necessarily subjective, and was based on logical considerations and observation of the differences in pressure distribution between children and adults. The primary differences are a matter of scale: pressure distributions of adults are generally wider and include higher pressures than those of children. Consequently, most of the tested parameters relate to either the dimensions of the seat contact area or the amount of pressure applied. The calculated parameters ranged from the simple (maximum lateral contact width) to the computationally complex (third mass moment calculated with respect to the second principal component).

Some of the simplest of the parameters were the most useful. The analyses demonstrated that the overall size of the seat contact area and the aggregate pressure on the seat are the best predictors of occupant body weight in this data set. Some parameters that have been proposed as occupant classifiers, such as the distance between the ischial peaks under the buttocks, showed no discrimination ability, even in the idealized (normal-posture) scenario.

When parameters were assessed with a wide range of postures, the occupant-classification performance of all of the parameters decreased, but pseudoweight (sum of the pressure times area) demonstrated a clear advantage. The performance of the parameters examined in this study as classifiers in an actual auto would depend on the distribution of postures. In the dataset from this study, leaning and extremely reclined postures are each as prevalent as normal postures, while normal postures would probably predominate in an actual vehicle seat. The expected performance of these classification parameters in a field application may lie between the performance in the idealized (normal-posture) scenario and the all-postures analysis.

The quantitative performance of the OCATDs with respect to pressure distribution is very good. Among the top ten classification parameters, the OCATDs generally differ by less than one standard deviation from the targets (that is, one standard deviation of the parameter distribution obtained from the human pressure distributions). In percentage terms, the deviations from the targets are generally less than five percent. Perhaps more importantly, the discrepancies are also small with respect to the differences between the OCATD5 and OCATD6 targets. For example, the observed PeakRowWidthP10 value for the OCATD6 is 20.0 sensor units, compared to a target value of 20.6 sensor units, a difference of about three percent. The OCATD5 target for the same parameter is 27.7 sensor units, a difference in target values of 7.1. The discrepancy in OCATD6 performance is only about 8 percent of the difference in target values between the OCATD5 and OCATD6. By all of these measures, the OCATD6 is very close to its target on this parameter. It should be noted that the discrepancies on width measures are generally less than one sensor unit (12.5 mm), indicating that the granularity of the measurement may be artificially inflating the discrepancy, even though five measurements were averaged for each observed parameter value. Examining a number of the width measures shows that the discrepancies are both positive and negative, supporting the conclusion that, overall, the width of the OCATD pressure distributions are as close to their targets as can be determined using this sensor system.

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